

PCT/IB04/50985

20190
REC'D 16 AUG 2004
WIPO PCT

PA 1177286

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

June 02, 2004

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A FILING DATE UNDER 35 USC 111.

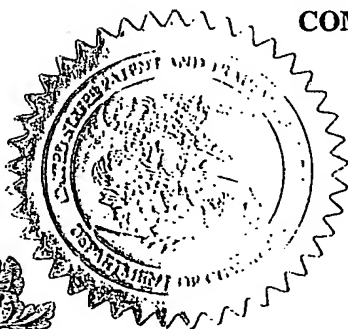
APPLICATION NUMBER: 60/482,099

FILING DATE: June 24, 2003

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS



H. L. Jackson
H. L. JACKSON
Certifying Officer

PATENT APPLICATION SERIAL NO. _____

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

06/26/2003 SDENB001 00000098 141270 60482099

01 FC:1005 160.00 DA

PTO-1556
(5/87)

*U.S. Government Printing Office: 2002 — 489-257/59033

06/24/03

17598 U.S. PTO

PROVISIONAL APPLICATION COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION under 37 CFR 1.53(b)(2).

19249 U.S. PTO

60/482099

06/24/03

Docket Number US030190		Type a plus sign (+) inside this box	
INVENTOR(S) / APPLICANT(S)			
LAST NAME	FIRST NAME	MIDDLE INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)
Maznev	Alexei		Marblehead, MA
TITLE OF THE INVENTION (280 characters max)			
OPTOACOUSTIC METHOD FOR MEASURING SURFACE PROFILE ON STRUCTURES CHARACTERIZED BY SUB-MICRON LATERAL FEATURE SIZE			
CORRESPONDENCE ADDRESS			
Philips Intellectual Property & Standard 345 Scarborough Road P.O. Box 3001 Briarcliff Manor, NY 10510-8001			
STATE	New York	ZIP CODE	10510 COUNTRY U.S.A.
ENCLOSED APPLICATION PARTS (check all that apply)			
<input checked="" type="checkbox"/> Specification	Number of Pages	10	<input type="checkbox"/> Small Entity Statement
<input checked="" type="checkbox"/> Drawing(s)	Number of Sheets	2	<input type="checkbox"/> Other (specify)
METHOD OF PAYMENT (check one)			
<input type="checkbox"/> A check or money order is enclosed to cover the Provisional filing fees	PROVISIONAL FILING FEE AMOUNT (\$)		\$160.00
<input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge filing fees and credit Deposit Account Number: 14-1270			

S:\WX\PHUS\US030190-DPROV.doc

1

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☒

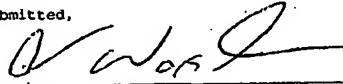
No,

☐

Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,

SIGNATURE



Date 6/24/03

TYPED or PRINTED NAME AARON WAXLER

REGISTRAR NO. 48,027

☐

Additional inventors are being named on separately numbered sheets attached hereto

CERTIFICATE OF EXPRESS MAILING

Express Mail Mailing Label No, EV 312 069 896 US
Date of Deposit June 24, 2003

I hereby certify that this paper and/or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 C.F.R. 1.10 on the date indicated above and is addressed to the Commissioner for Patents, Alexandria VA. 22313-*1450

Burnett James
Typed Name


Signature

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of

ALEXEI MAZNEV

Serial No.:

Filed: CONCURRENTLY

Title: OPTOACOUSTIC METHOD FOR MEASURING SURFACE PROFILE ON
STRUCTURES CHARACTERIZED BY SUB-MICRON LATERAL FEATURE SIZE

Atty. Docket

US030190

Group Art Unit No.:

Commissioner for Patents
Alexandria, VA 22313-1450

AUTHORIZATION PURSUANT TO 37 CFR 91.136(a) (3)
AND TO CHARGE DEPOSIT ACCOUNT

Sir:

The Commissioner is hereby requested and authorized to treat any concurrent or future reply in this application requiring a petition for extension of time for its timely submission, as incorporating a petition for extension of time for the appropriate length of time.

Please charge any additional fees which may now or in the future be required in this application, including extension of time fees, but excluding the issue fee unless explicitly requested to do so, and credit any overpayment, to Deposit Account No. 14-1270.

Respectfully submitted,

By 

Aaron Waxler, Reg. 48,027
Patent Agent
(914) 333-9608

S:\WX\PHUS\US030190-DPROV.doc

RETURN COPY OF THE
ID ABSTRACT TO:
FOR ADMIN USE ONLY

SUB 27
ID 703621
PS ALB
MSC SIV
DIV WAXL

EXPORT CONTROL
NUMBER (ECCN)

NLR EARX

ECO INITIALS

En 20 Sept 2002

FOR CIP USE ONLY

PHILIPS ELECTRONICS NORTH AMERICA CORPORATION

DISCLOSURE OF INVENTION

THIS DESCRIPTION SHOULD BE SUPPLEMENTED BY ATTACHING COPIES OF RELEVANT DOCUMENTS, SUCH AS
PUBLISHED ARTICLES OR PATENTS, PRODUCT BROCHURES, ENGINEERING NOTEBOOK PAGES AND DRAWINGS.

DESCRIPTIVE TITLE OF THE INVENTION: Optoacoustic method for measuring surface profile on
structures characterized by sub-micron lateral feature size

INVENTOR #1: Alexei Maznev Sr. Scientist Philips Analytical, Supply Center Boston
Name (Print) Job Title Division / Location

Alex.maznev@philips.com

E-Mail address

Michael Gostein

Manager's Name

6 Saturn Rd., Marblehead MA 01945

Home Address

Russian Federation

Country of Citizenship

INVENTOR #2:

Name (Print)

Job Title

Division / Location

E-Mail address

Manager's Name

Home Address

Country of Citizenship

INVENTOR #3:

Name (Print)

Job Title

Division / Location

E-Mail address

Manager's Name

Home Address

6201 V L 103 2002

Country of Citizenship

D:\MAZNEV\PATENTS\ETCH DEPTH\DISCLOSURE OF INVENTION - ET@BDEPTH.DOC
Revision June 11, 2001

1. **PRIMARY CONTACT**
Who should CIP contact for further technical information about the invention and information about its planned use or public disclosure?

Inventor Name: Alexei Maznev

2. **PRESENT STAGE OF THE INVENTION**

☒ Idea ☐ Research ☐ Development ☐ Manufacture

3. **GOVERNMENT CONTRACT INVENTION**

Was the invention made under a government contract? ☐ Yes ☒ No

4. **PLEASE PROVIDE A TWO OR THREE SENTENCE SUMMARY OF YOUR INVENTION and include and underline KEY WORDS which might be useful in searching for relevant patents or publications:**

Photoacoustic transient grating technique also known as ISTS (Impulsive Stimulated Thermal Scattering) is applied to measuring profile of periodic structures with sub-micron feature size such as arrays of etched trenches. The measurement is based on the dependence of the surface acoustic wave velocity on the depth of the profile.

5. **PRESENT STATE OF THE ART**

Briefly describe the closest already-known technology that relates to the invention. This would include, for example, already existing products, methods or compositions which are known to you personally or through descriptions in publications.

1. ISTS technique implemented in Philips Analytical's Impulse/Emerald instruments is primarily used for film thickness measurement. It would be straightforward to use this technique to measure the etch depth of a film on a substrate if the size of the etched area is of the order of or larger than the probe laser spot i.e. typically $\geq 30 \mu\text{m}$, in which case such measurement will be equivalent to measuring the film thickness inside and outside the etched area.

2. Scanning atomic force microscopy (AFM) is used to measure profile of sub-micron structures.
3. Scatterometry (measurement of the angular distribution of light scattered by the structure) is used to measure the surface profile of sub-micron structures. Unlike AFM, this is an indirect method based on the mathematical modeling of light scattering, and the feature size should be larger than at least a half of the optical wavelength.

D:\AMAZNEVPATENTS\ETCH DEPTH\DISCLOSURE OF INVENTION - E1\@BDEPTH.DOC
Revision June 11, 2001

4. An effect of periodic surface relief on the velocity of SAWs measured by the ISTS technique has been previously observed (see L. Dhar and J.A. Rogers, Appl. Phys. Lett. 77, 1402 (2000)). However, it has not been proposed that the method could be used to measure the etch profile depth.

(ADD LINES AS NECESSARY, IF COMPLETING ON COMPUTER, OR ATTACH ADDITIONAL PAGES)

6. **ADVANCEMENT IN STATE OF THE ART**

Briefly describe the unique advancement achieved by the invention. This may be done, for example, by describing a problem with the prior art that is solved or specific objects that are achieved by the invention.

1. Unlike AFM and scatterometry, the proposed method does not have limitations related to high aspect ratio or small feature size of the structure

2. Compared to AFM, the method has an advantage of being an all-optical technique providing faster measurements and more suited for in-line process control. The profile depth is obtained in a single measurement vs. a linear scan needed in a measurement by AFM

3. Compared to scatterometry, the method has an advantage of simple and straightforward data analysis. The only measured parameter is the SAW frequency. Typically, the smaller the frequency, the larger is the profile depth.

4. The invention extends the range of applications of Impulse/Emerald film thickness measuring instruments.

(ADD LINES AS NECESSARY, IF COMPLETING ON COMPUTER, OR ATTACH ADDITIONAL PAGES)

7. **WHAT IS THE BEST WAY YOU KNOW OF TO IMPLEMENT THE INVENTION?**

Briefly describe the invention and how it achieves the advancement described in paragraph 6

Attached on additional pages

(ADD LINES AS NECESSARY, IF COMPLETING ON COMPUTER, OR ATTACH ADDITIONAL PAGES)

*****PLEASE NOTE: IF WE DECIDE TO FILE AN APPLICATION ON THIS INVENTION, THE ATTORNEY WRITING THE APPLICATION WILL NEED THIS INFORMATION FROM YOU IN AS MUCH DETAIL AS POSSIBLE IN ORDER TO COMPLETE THE APPLICATION.

8. **DISCLOSURE OUTSIDE OF PHILIPS**

If the invention has been or will be disclosed publicly or to anyone other than a Philips' employee, describe to whom (person / company), date and where.

The invention has not been disclosed outside of Philips

9. **PUBLICATION**

Has a description of the invention been published or submitted for publication? ☐ Yes ☒ No

If "yes", please list each occurrence:

Date

Publication/Submission

10. **PLEASE INDICATE THE PRODUCT OR SERVICE IN WHICH YOUR INVENTION MOST LIKELY WILL BE USED:**

Philips Analytical's optoacoustic product line (Impulse/Emerald)

--

INVENTOR #1:

Signature

Date

A. Hey 09/13/02

INVENTOR #2:

Signature

Date

INVENTOR #3:

Signature

Date

Measuring depth of sub-micron trench arrays by ISTS

I. Outline of the method.

In the prior art, laser-induced transient grating technique, or ISTS, has been used to measure film thickness via measuring the phase velocity of Surface Acoustic Waves (SAWs) propagating in the filmstack. If the film is patterned e.g. by etching, it would be straightforward to use ISTS for measuring the etch depth if the size of the etched area is large compared to the SAW wavelength (typically 2-10 μm). In this case measuring the etch depth means simply measuring a change in the film thickness (see Fig.1). Note that it can only be done for a thin film on a substrate made of different material so that the SAW velocity be dependent on the film thickness. The prior art method will not work at all if one needs to measure surface profile of a bulk sample, e.g. a silicon wafer.

In the state-of-the-art integrated circuit manufacturing, typical pattern feature size is of the order of 0.1 μm i.e. much less than the SAW wavelength in an ISTS measurement. Although larger features may be also present within a die, it is the smallest features that are most likely to be misprocessed during lithography and etching, and, consequently, require process control metrology. According to the current invention, ISTS can be used to measure depth profile of a periodic structure with near- or sub-micron feature, e.g. a periodic array of trenches etched either in a thin film or in a silicon substrate (see Fig.1). The measurement is based on the fact that the SAW phase velocity is affected by periodic surface relief. This effect have been reported previously [1-2], but the application of the effect to measuring surface profile has not been proposed. Also, no studies have been done for high-aspect-ratio sub-micron structures which are of the most interest for practical applications.

According to the invented method, the measurement process is similar to an ISTS measurement known from the prior art, except of the fact that the excitation and detection of SAWs is performed on a patterned sample with surface profile characterized by a period of the order or less than 1 μm . The measurement yields the SAW frequency at a defined wavelength, from which the SAW phase velocity is calculated. The data are analyzed with the help of an analytical or empirical model to determine a parameter of the profile, typically the trench depth or width / space ratio.

II. Theoretical model for high aspect ratio trench arrays.

Previous theoretical work [1] was done for shallow surface relief permitting the use of perturbative approaches. Accurate analysis of high aspect ratio structures would require finite element calculations. Here, we are considering an approximate model in order to obtain at least an estimate of the effect of high aspect ratio trench array on SAW propagation. The model applies to periodic arrays of trenches such as those shown in Fig. 1, with the period smaller than the trench depth. The model assumes that if the period of the structure is small with respect to both SAW wavelength and thickness of the structure, the structure can be treated as a homogeneous material with effective elastic properties. In Ref. [3], it was shown how to calculate the effective elastic properties of a layered structure from the properties of constituent materials. The layered structure is effectively described as a transversely isotropic medium with the symmetry axis perpendicular to the layers, which is described by 5 independent effective elastic constants. The same method can be applied to a trench array if vacuum is treated as one of the constituent materials of the structure. From the equations of Ref.[3], we obtain the following equations expressing effective density ρ^* and elastic constants C_{ij}^* of the trench array through the density ρ and elastic constants C_{ij} of the material:

$$\begin{aligned}\rho^* &= h\rho \\ C_{11}^* &= h\left(C_{11} - \frac{C_{12}^2}{C_{11}}\right) \\ C_{66}^* &= hC_{44} \\ C_{13}^* &= C_{33}^* = C_{44}^* = 0\end{aligned}\tag{1}$$

where h is the ratio of the space between the trenches to the period of the structure. It can be expressed through the trench width/space ratio as $h=1/(1+w/s)$. The notations in Eq.(1) assume that the z -axis is perpendicular to the trenches.

For SAW propagation along the x -axis i.e. along the trenches, a transversely isotropic medium with the z symmetry axis is equivalent to an isotropic medium and the only elastic constants that matter are C_{11}^* and C_{66}^* . Therefore, a standard computer code for SAW propagation in a film/substrate structure can be used to analyze this case. Analysis of the propagation across the trenches is more complicated because some acoustic velocities are equal to zero and the standard code cannot handle the situation. For this case, I did a simplified analysis, modeling a trench array as a mass loading lacking any elastic strength.

Fig. 2 presents the calculated dependence of the SAW velocity on the trench depth for trench arrays with width/space ratios 1:1 and 1:3 fabricated in Si and in a 1 μ m-thick thermal oxide film on

Si. The calculations were done for SAW wavelength $6\text{ }\mu\text{m}$. The calculations show that there is a significant dependence of the SAW velocity on both the trench depth and width/space ratio, particularly for SAW propagation across the trenches. In order to estimate the repeatability of the trench depth measurements, let us assume that the repeatability of the SAW velocity measurements is $\sim 0.5\text{ m/s}$ (which corresponds to the frequency measurement repeatability of 0.1 MHz). For a trench depth of $5000\text{ }\text{\AA}$ and SAW propagation perpendicular to the trenches, the results presented in Fig.(2) yield a repeatability estimate of $\sim 7\text{ }\text{\AA}$ (or 0.14%) for 1:1 width/space ratio trenches in Si and $\sim 20\text{ }\text{\AA}$ (or 0.4%) for trenches in the oxide film.

It should be noted that variations in trench depth and width have different effects on SAW velocity parallel and perpendicular to the trenches. An increase in the trench width increases the parallel velocity but decreases the perpendicular velocity while an increase in the trench width/space ratio increases the SAW velocity in both directions. This fact indicates that the measurements with SAW propagation along and across the trenches could be combined in order to determine both trench depth and width/space ratio.

III Experiment

Experiment was done at an acoustic wavelength of $6\text{ }\mu\text{m}$ on an array of $1\text{ }\mu\text{m}$ -wide trenches with 1:1 width/space ratio etched in an $8000\text{ }\text{\AA}$ -thick layer of CVD oxide on Si, and covered with $\sim 250\text{ }\text{\AA}$ of PVD Ta and $\sim 1000\text{ }\text{\AA}$ of PVD Cu (see Fig.3). Note that this structure does not correspond to the theoretical model considered above because of the presence of the metal coating and also because the aspect ratio of the trenches is not high enough and the structure period is not too small compared to the wavelength. Therefore, the experiment was performed not in order to quantitatively verify the theoretical model but rather in order to demonstrate that a structure with deep trenches yields a good signal for SAW propagation direction both parallel and perpendicular to the trenches and also that there is a significant effect of the surface profile on the SAW velocity.

Fig. 4 presents the signal waveforms obtained in the unpatterned area of the sample and on the trench array with SAW propagation parallel and perpendicular to the trenches. It can be seen from the waveforms, that for the perpendicular propagation, the effect of the surface relief on the signal is particularly strong and that it causes a significant decrease in the SAW velocity. Table 1 lists the values of the SAW velocity obtained from the measured waveforms. The fact that the presence of the trenches increases the SAW velocity for the parallel propagation and decreases it for the perpendicular propagation qualitatively agrees with the theoretical model.

Reference

1. L. Giovannini et al., Phys. Rev. Lett. 69, 1572 (1992)
2. L. Dhar and J.A. Rogers, Appl. Phys. Lett, 77, 1402 (2000).
3. M. Gostein and A.A. Maznev, invention disclosure #703048

D:\MAZNEV\PATENTS\ETCH DEPTH\DISCLOSURE OF INVENTION - ET@BDEPTH.DOC
Revision June 11, 2001

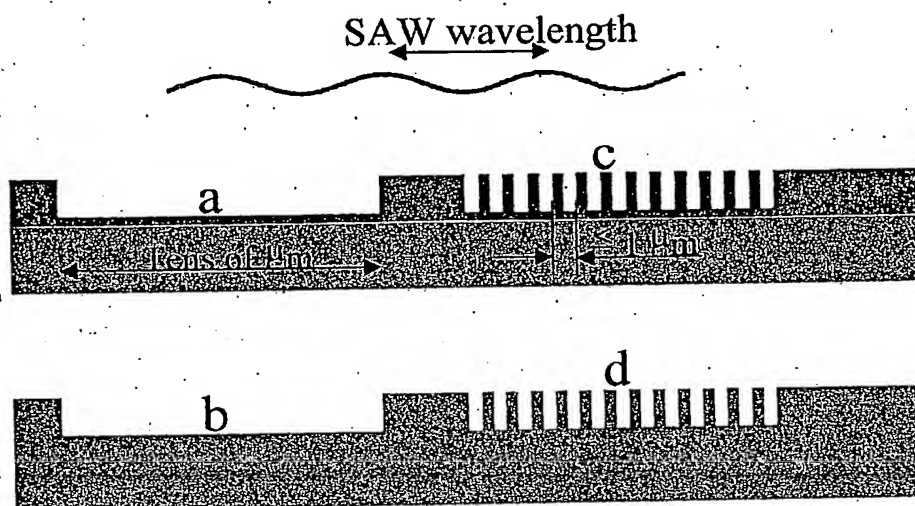


Fig. 1 Patterned film on a Si substrate (top) and patterned Si substrate (bottom).

The method proposed in the invention measures the trench depth on structures (c) and (d). Structure (a) can be measured by a prior art method, structure (b) cannot be measured by ISTS as of now.

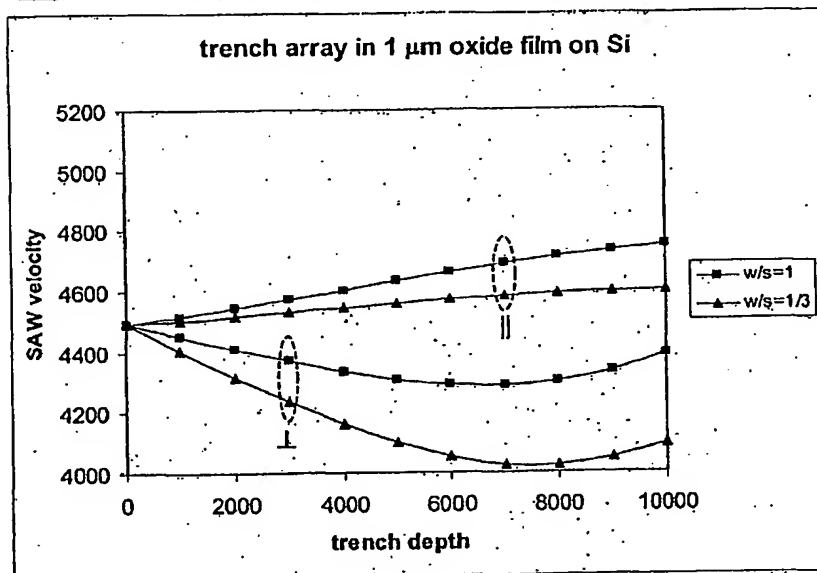
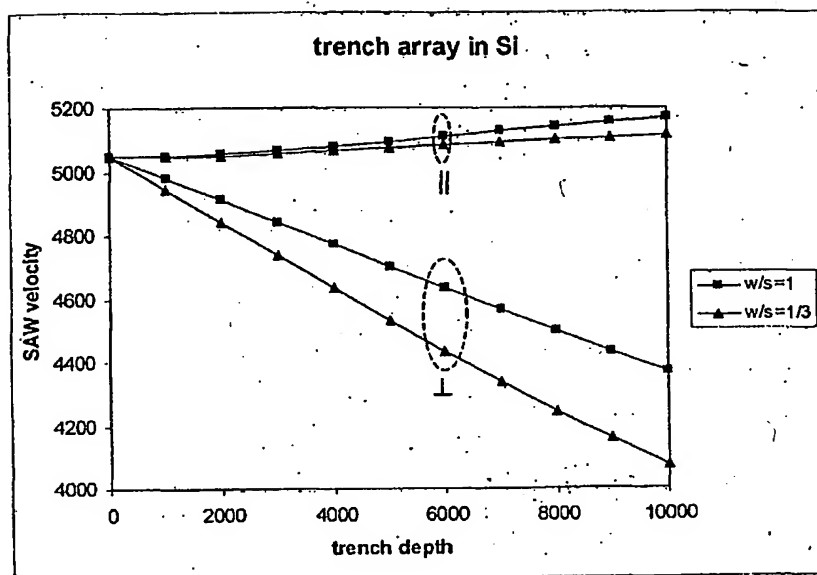


Fig.2 Calculated dependence of the SAW velocity on the trench depth for trench arrays with width/space ratios 1:1 and 1:3 fabricated in Si (top) and 1 μ m-thick thermal oxide film on a Si substrate (bottom) for SAW propagation parallel (||) and perpendicular (\perp) to the trenches.

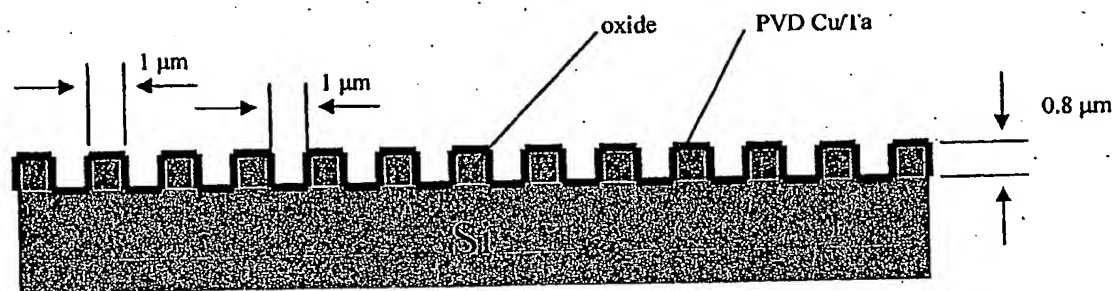


Fig. 3 Structure measured in the experiment

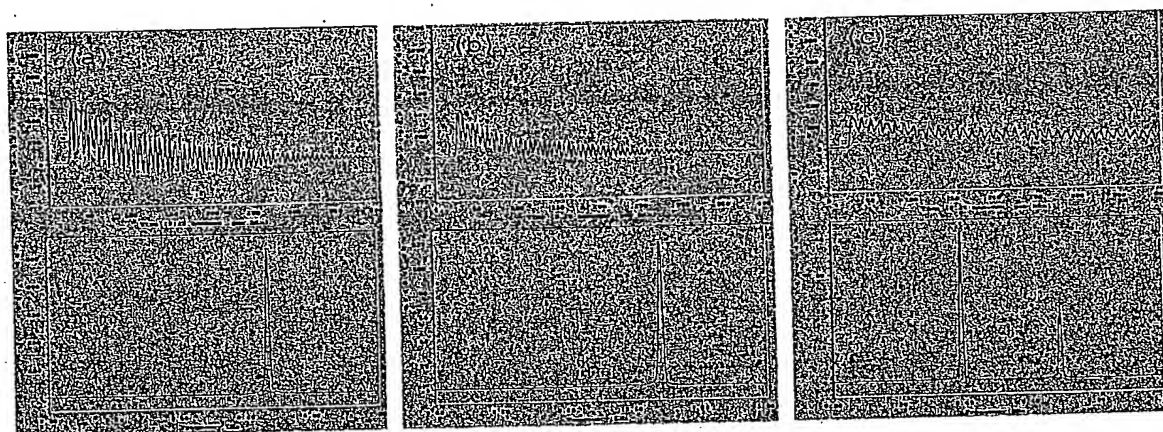


Fig. 4 Signal waveforms obtained at acoustic wavelength $6 \mu\text{m}$ on a sample with filmstack 1000 \AA Cu / 250 \AA Ta / 8000 \AA oxide / Si. (a) unpatterned area of the sample, (b) 1 mm width $\times 1 \text{ mm}$ space trench array, SAW propagation parallel to the trenches; (c) SAW propagation perpendicular to the trenches.

Measurement location	SAW velocity (m/s)
Unpatterned area	3930
Trench array, parallel	4016
Trench array, perpendicular	2299

Table 1. SAW velocities determined from the waveforms presented in Fig. 4.